EQUIPMENT DEVELOPMENT AND TEST REPORT
NO. 2400-4

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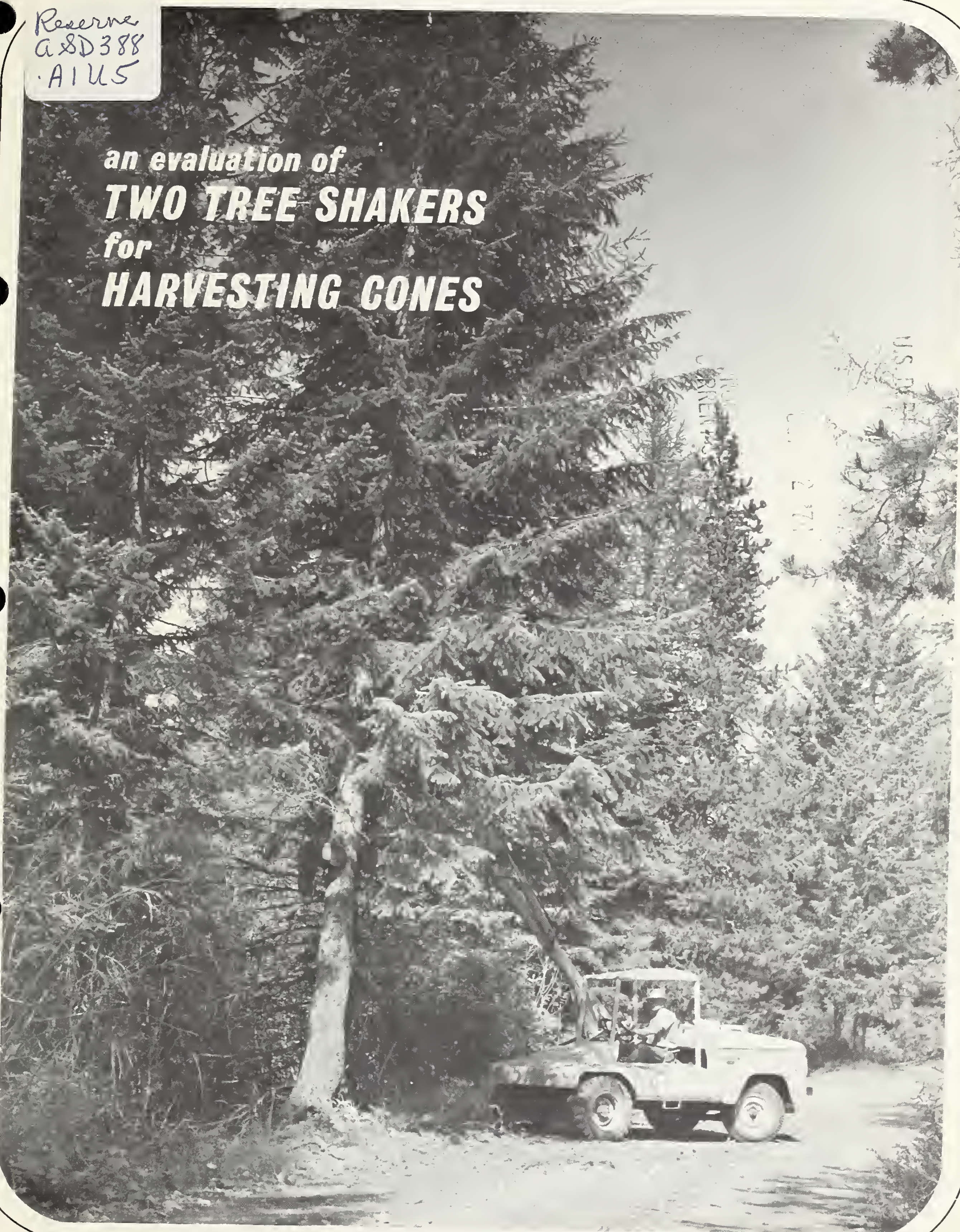

USDA FOREST SERVICE
EQUIPMENT DEVELOPMENT CENTER
MISSOULA, MONTANA

Equipment Development and Test Report
No. 2400-4

AN EVALUATION OF TWO TREE SHAKERS FOR HARVESTING CONES

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U.S. Department of Agriculture
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ABSTRACT

The Farmhand Shaker, manufactured by Farmhand Machinery Co., and the Shock Wave Shaker, manufactured by Orchard Machinery Corp., two tree shaking machines designed for harvesting fruit and nuts, were evaluated in Montana and northern Idaho for removing cones from Engelmann spruce (*Picea engelmanni),* ponderosa pine (*Pinus ponderosa*), grand fir (*Abies grandis*), and Douglas-fir (*Pseudotsuga menziesii*). The Farmhand Shaker removed cones from Engelmann spruce, grand fir, and Douglas-fir, and effectively shook trees up to 22 inches diameter at breast height (dbh). The Shock Wave Shaker removed cones from all four species and effectively shook trees up to 36 inches dbh.

Most of the cones were removed within 5-10 seconds of shaking at approximately 400 to 900 cycles per minute. Among the variables found to affect cone removal were dbh, trunk taper, cone distribution, crown density, cone size, and species.

Thrust of the Shock Wave Shaker can be increased by substituting heavier weights in the shaking head and a more powerful engine. Increasing force of the Farmhand Shaker would require a major redesign.

Work on this project was done under ED&T 1553 for the Division of Timber Management.

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INTRODUCTION

Since 1964 the Missoula Equipment Development Center has been evaluating mechanical devices for harvesting cones to be used as a source of seed in forest nurseries. Of the methods tried, shaking devices showed the most promise. The first shakers tried were designed to shake grain and other loose materials from bins and boxcars. Clamped to trees, the shakers were not powerful enough to remove large quantities of cones; nevertheless, enough cones fell to warrant further investigation of the shaking concept.

The Center consulted experts in orchard harvesting at the University of Southern California at Davis and the four major manufacturers of commercial tree shakers used in fruit and nut orchards. Two different machines, the Farmhand and the Shock Wave, representing the two most successful designs, were selected for evaluation.

In the fall of 1968, the two shakers were evaluated in Montana and northern Idaho. The objectives of the evaluation were (1) to determine the effectiveness of the machines for harvesting cones and (2) to determine if the machines could be modified to make them more effective. The evaluation was restricted to four species of conifers. No attempt was made to determine the cost of collecting cones by shaking.

This report presents the results of the evaluation — the machines tested, the species and sizes of trees shaken, the quantities of cones removed by each machine, and various factors that influence cone harvest.

DESCRIPTION OF MACHINES

The Shock Wave Shaker (fig. 1), manufactured by the Orchard Machinery Corp., Yuba City, Calif., is mounted on a 1½-ton truck chassis that has been modified. The chassis has been shortened and the steering wheel has been moved to the rear so, in effect, the vehicle is driven in reverse. Because the chassis was originally designed for front wheel steering, the machine should not be driven faster than 20 miles per hour.

With the boom stowed, the shaker can be towed on the highway by a vehicle of at least 8,000 lb GVW. The chassis is towed with the steerable wheels trailing. To prevent damage to the automatic transmission during towing, the engine must be idled in neutral or the drive shaft must be disconnected.

Shaking action is produced by two weights counter-rotating around two parallel axes (fig. 2). Using pulleys of two different diameters changes the direction of shake from unidirectional to omnidirectional. To minimize bark damage, the clamp of the shaking head was fitted with pads. The vibrating head can be clamped as high as 12 feet on a tree and can still be kept perpendicular to the trunk.

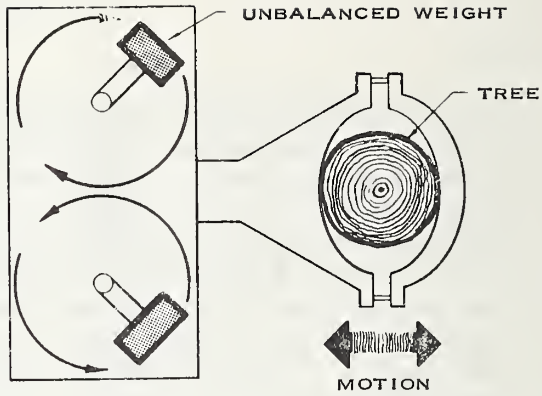

Figure 2.—Shaking head of Shock Wave Shaker.

Figure 1.—Shock Wave Shaker.

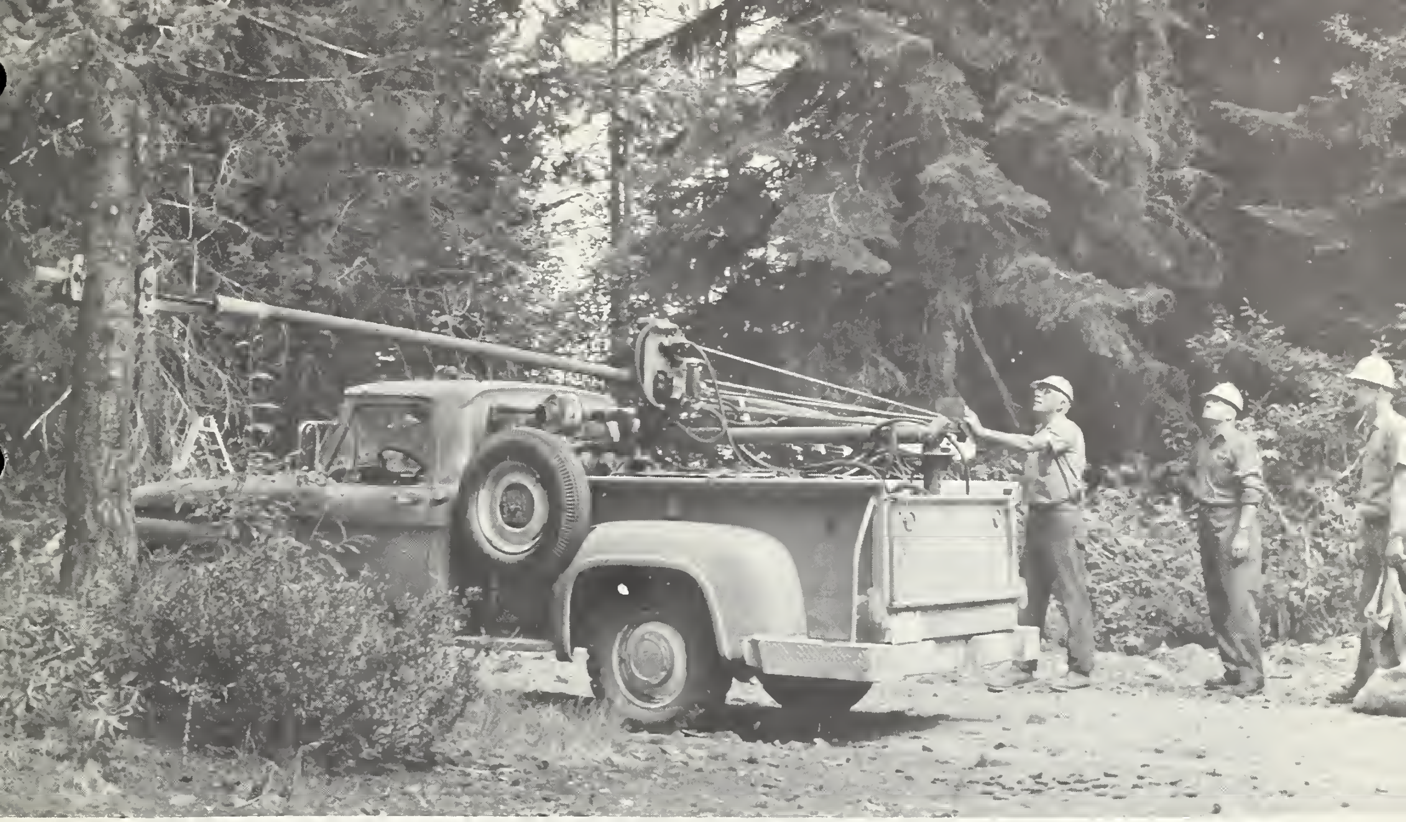

Figure 3.—Farmhand Shaker mounted on a pickup truck.

Two models of the Shock Wave are available – one for trees up to 22 inches dbh and another model for trees up to 36 inches dbh. This Center selected the 36-inch model, which costs approximately $10,000, and weighs about 6,000 pounds. Total weight of the shaking head was 700 lb.

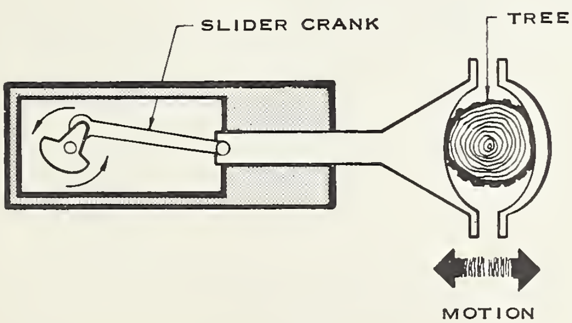

Figure 4.—Shaking head of Farmhand Shaker.

The Farmhand Shaker (fig. 3), manufactured by the Farmhand Machinery Co., Elk Grove, Calif., incorporates a hydraulically propelled slider-crank (fig. 4). It is offered mounted on a modified truck chassis, or as a kit that the purchaser can mount on a light truck or tractor. For this evaluation, the kit was installed in a ¾-ton pickup along with a 50 hp Wisconsin engine and a hydraulic pump. (An engine of at least 50 hp is required to develop maximum force.) The kit cost $4,200, and the complete installation weighed 1,500 pounds.

Fitted with a 136-pound shaking head, and with the engine running at 1,000 rpm, the Farmhand will develop up to 8,000 ft-lb of thrust. However, this is slightly beyond the manufacturer's recommendations, so during the tests engine speed was held to 800 rpm. The shaking head is not raised horizontally, but is pivoted upward on the boom; therefore, shaking force is not perpendicular to the tree trunk.

TEST PROCEDURE

Testing was done between September 4 and September 17, 1968. Shaking of Douglas-fir, Engelmann spruce, and grand fir was done on the Coeur d'Alene National Forest in Idaho because these species were abundant and insect damage to cones was light. Ponderosa pine cones were collected on the Lolo Forest in Montana.

In the early tests, the following data were recorded: species, dbh, tree height, crown height, number of bushels of cones on the tree, and the amount of cones removed. As testing progressed, it became apparent that many more variables than had been anticipated affected cone removal. Cone distribution within the crown, crown width, and specific gravity of the cones were added to the list of data to be recorded. The quantity of cones in bushels on the tree and the percentage removed were estimated. During the first two weeks, tarps were spread under the trees, and the cones were counted to verify estimates of the percentage removed. The two machines were alternated from tree to tree, to eliminate effects of elevation, terrain, etc.

Because many old, opened cones hung on ponderosa pine, even after shaking, a slightly different method was devised for estimating cone removal on this species. Trees were shaken, and the new, unopened cones that fell were counted. Then, using binoculars for accurate identification, the new cones still clinging to the trees were counted.

At the beginning of the tests, the goal was to remove as many cones as possible. Trees were shaken continuously until cone fall diminished. As a result of prolonged shaking, sometimes 8 to 12 feet of top and some branches were broken off. When it became apparent that prolonged shaking did not produce many more cones, shaking was controlled to reduce tree damage. After about 25 trees had been shaken, the operator knew the frequency, power setting, and duration of shaking that would remove cones and not break the tops of the trees. The frequency and duration of shaking that produced good cone fall and did not break treetops was noted.

Next, a line of bushel baskets was set out radially from each tree to determine the drop zone of the cones. Cones were collected by hand and quantity was measured in bushels. Each tree was examined for damage, such as top removal. No attempt was made to assess damage done to branches or roots. Trees were tagged and later re-examined to see if trees shaken differed in any way from the trees not shaken.

The Shock Wave Shaker was then evaluated under orchard conditions provided by a thinned stand of ponderosa pine on the Coeur d'Alene Nursery. The time required for the Shock Wave Shaker to be moved from one tree to another and simulate shaking the tree was recorded. Time required to pick up cones was not included. The objective of this test was to learn how many trees per minute could be shaken in an orchard.

RESULTS AND DISCUSSION

Table 1 shows the average rate of cone removal in quantity (bushels) and percentage for both machines. The Farmhand Shaker removed a slightly higher quantity of grand fir cones than the Shock Wave. This is probably the result of a statistical fluctuation, because the machines appeared to be equally effective. A report published by the Forest Service Southern Forest Experiment Station, "Mechanized Cone Harvesting Production Study," showed that a Shock Wave Shaker shook 213 slash pine trees and averaged 76 percent removal or .44 bushels per tree. This is comparable to the performance of the Shock Wave Shaker in the Center's tests described in this report.

Trees shaken were examined a year after this evaluation. Other than top removal on some trees, no adverse effects were noted.

SHAKING MACHINES

Shock Wave Shaker.—The Shock Wave Shaker as presently designed could be used to harvest cones along roadsides and in gentle terrain. The economic feasibility of using the machine is beyond the scope of this report and would depend on the cost of cones from other sources, the abundance of cone-bearing trees, etc. The Shock Wave could be modified to produce more power by providing heavier weights in the shaking head and a larger engine to drive them. Other parts of the shaker appear to be strong enough to handle increased force.

Farmhand Shaker.—The Farmhand Shaker was operated at the limits of the design, and any attempt to increase shaking force would require major redesign. Since the shaking head meets the tree at an angle, shaking force is not perpendicular to the tree trunk, which reduces the effectiveness of the shaker. The 50 hp engine used in this evaluation was adequate for the head that was used. The hydraulic system controlling the clamp permits the clamp to open slightly after a few seconds of vibration, which reduces the force transmitted to the tree and tends to increase bark damage. With the present controls, two men are required to operate the machine, and they must stand where they might be struck by falling limbs.

Table 1.—*Cone removal by species*

	FARMHAND			SHOCK WAVE		
	Percent	Bushels	Maximum dbh (in.)	Percent	Bushels	Maximum dbh (in.)
Engelmann spruce	51	.50	20	66	.90	32
Ponderosa pine	0	0	16	75	.63	22
Grand fir	93	.47	22	94	.35	36
Douglas-fir	36	.44	18	52	.42	28

TREE SPECIES

Appendix A presents field data tabulated in order of increasing dbh. Data were analyzed to determine the correlation of cone removal to parameters such as dbh, tree height, and crown height. Statistical methods and equations are shown in Appendix B.

No single parameter showed a strong correlation for all four species with either machine. Dbh was selected as the most useful parameter to use for estimating cone removal for Douglas-fir, ponderosa pine, and grand fir. For Engelmann spruce, tree height was selected. Using the least squares technique (Appendix B), the relationship of these parameters to cone removal were graphed and are presented in Appendix C. As shown by the confidence interval, cone removal cannot be estimated with great precision, probably because trunk taper, crown density, and other variables can have considerable damping effect.

Douglas-fir.—This species has many characteristics that make it difficult to shake free its cones. The dense crown damps vibration, the cones are found almost all the way to the ground, and the tops break easily. As dbh increases, cone removal decreases (fig. 5, Appendix C). Dbh seems to be the most useful parameter for predicting cone removal.

Ponderosa pine.—The Farmhand Shaker did not harvest a significant amount of cones from ponderosa pine. The Shock Wave averaged 75 percent removal. Dbh is probably the most useful indicator of harvest success. The ratio of crown height to tree height and the ratio of dbh to tree height are better correlated to harvest, but are less useful in the field. A dense crown growing close to the ground and the stiffness produced by abrupt taper have a damping effect. The cones are fastened very securely. Some of the bushier specimens have cones that are very difficult to remove in the lower part of the tree.

Grand fir.—Both shakers harvested nearly all the cones from grand fir. The Farmhand handled trees up to 22 inches, the Shock Wave handled trees up to 36 inches. The slightly higher cone removal for the Farmhand shaker shown in table 1 is probably a statistical fluctuation because the Shock Wave Shaker appeared to be as effective as the Farmhand Shaker.

Engelmann spruce.—The most useful parameter for predicting cone harvesting is tree height. Spruce cones are easier to remove than Douglas-fir cones, but tree shape has an influence on cone removal. There may be an upper limit on tree size for successful shaking, but this was not apparent in the height (125 ft) of the trees tested in this study.

Both the percent of cones and volume of cones removed seem to decrease as dbh and height increase. Due to scatter in the data collected, it was not possible to determine if the reduction was linear or there was some cut-off point at a larger tree size. Trunk taper has a profound effect on cone removal. Abruptly tapered specimens proved very resistant to shaking. Generally, the smaller the crown in relation to tree height, the more effective is shaking in removing cones. The larger and more dense the crown, the more difficult it is to remove cones.

Cones at the top, or upper third of the tree crown, are removed first. Cones in the lower third of the crown are difficult to remove on all species. Within a given species, there is a higher percentage of removal for larger and heavier cones. Cones that are badly insect-damaged are relatively difficult to remove. This may be because insect-damaged cones are small, lightweight, and the stems are more securely attached to the branches.

Ripeness of the cones may have an important influence on cone removal. Good data were not obtained on the effect of ripeness. Grand fir cones, when green, were difficult to remove with the Farmhand Shaker. It was not possible to return to these same trees for tests after the cones ripened. Ponderosa pine cones may be more easily harvested before complete ripening and still produce viable seed.

Attachment height of the clamp, from 2 to 8 feet above ground, seems to have little influence on cone removal. Some trees were shaken down to 2 feet from the ground and later at a higher point with no apparent difference. On long, slim trunks an attachment point of 12 feet developed a standing wave between the shaker head and the ground. Attaching the head 6 feet above ground was more effective.

The highest frequency for efficient shaking appears to be about 800-1000 cycles per minute. At speeds higher than this there appears to be an out-of-phase resistance by the tree that results in a loss of energy, and there is no increase in either amplitude or shaking motion. The lower limit for good cone removal is 300 cycles per minute. Below this frequency, force dropped off too rapidly to be evaluated for effectiveness. Most of the cones will be removed within the first 5- to 10-second burst of shaking. Additional shaking increases the likelihood of tree damage. The efficiency of removal is determined by the amount of force exerted within the range of frequencies. Between 400 and 900 cycles per minute, the greater the force applied the more efficient the removal, and the larger size the tree that can be handled.

Mechanical harvesting works best where there are an abundance of cone-bearing trees close together. In the simulated shaking of thinned ponderosa pine on the Coeur d'Alene Nursery, the Shock Wave Shaker was timed at an average rate of two trees per minute. Under these orchard conditions, gathering cones from the ground, not shaking them from the tree, would be the most costly part of the operation.

The economy and efficiency of mechanical cone harvesting can be increased by providing catching devices under the trees, or machines that pick up the cones from the ground. Appendix D, figure 9 shows the dispersion of cones from a group of Douglas-fir. To catch 90 percent of the cones, the catching device would have to be 13 to 16 feet in radius.

CONCLUSIONS

The quantity of cones removed by shaking will vary with the machine used, tree species, and characteristics of the individual tree, such as size, shape, trunk taper, etc. The Shock Wave Shaker removed cones from all four species included in this evaluation – Douglas-fir, grand fir, Engelmann spruce, and ponderosa pine. The Farmhand Shaker removed cones from all species except ponderosa pine, which has cones that are difficult to shake loose. The Shock Wave removed cones from trees up to 36 inches dbh, the Farmhand from trees up to 22 inches dbh. Most of the cones fell within 5-10 seconds of shaking at 400-900 cycles per minute.

Force of the Shock Wave Shaker can be increased by using heavier weights in the shaking head and a more powerful engine to propel them. Force of the Farmhand Shaker cannot be increased because of design limitations. Both machines are restricted to harvesting cones along roads or on gentle terrain where a light truck can be driven.

APPENDIX A
CONE REMOVAL DATA
BY SPECIES

GRAND FIR—SHOCK WAVE SHAKER

Tree no.	Date	Dbh inches	Total height feet	Crown height feet	Cone removal percent	Cone removal bushels
110	10 Sep 68	10.6	60	40	99	0.13
112	10 Sep 68	11.8	60	30	99	0.13
8	4 Sep 68	12.6	60	54	99	0.33
113	10 Sep 68	12.8	58	32	99	0.13
114	10 Sep 68	14.2	64	35	99	0.13
68	7 Sep 68	14.6	93	75	97	0.13
109	10 Sep 68	14.8	66	46	99	0.25
207	13 Sep 68	14.9	61	37	90	0.30
60	7 Sep 68	15.5	87	74	98	0.25
208	13 Sep 68	15.5	61	47	90	0.45
1	4 Sep 68	16.0	84	74	98	0.75
69	7 Sep 68	18.5	97	80	96	1.00
206	13 Sep 68	18.8	67	45	80	0.75
64	7 Sep 68	19.5	114	64	95	0.13
63	7 Sep 68	20.8	115	60	99	0.13
71	7 Sep 68	21.4	118	96	98	0.13
72	7 Sep 68	21.6	86	60	99	0.50
70	7 Sep 68	22.6	89	73	90	0.25
65	7 Sep 68	26.3	135	86	85	0.33
56	7 Sep 68	29.4	135	88	95	0.25
82	7 Sep 68	29.6	112	83	99	0.25
58	7 Sep 68	36.9	100	70	75	1.00

GRAND FIR—FARMHAND SHAKER

Tree no.	Date	Dbh inches	Total height feet	Crown height feet	Cone removal percent	Cone removal bushels
68	7 Sep 68	14.6	93	75	97	0.12
4	4 Sep 68	15.2	105	95	80	0.20
57	7 Sep 68	16.5	110	88	99	0.12
86	9 Sep 68	17.2	71	55	90	0.25
2	4 Sep 68	20.2	106	88	97	1.75
62	7 Sep 68	20.4	123	71	95	0.13
54	7 Sep 68	21.0	99	66	96	Not recorded
10	4 Sep 68	22.0	107	87	95	0.75

DOUGLAS-FIR–SHOCK WAVE SHAKER

Tree no.	Date	Dbh inches	Total height feet	Crown height feet	Cone removal percent	Cone removal bushels
209	13 Sep 68	11.4	44	32	60	0.30
204	13 Sep 68	11.8	56	28	75	0.50
105	10 Sep 68	12.2	48	40	60	0.25
15	4 Sep 68	12.9	65	58	30	0.50
89	10 Sep 68	13.5	69	50	45	Not recorded
221	14 Sep 68	13.6	45	35	15	0.10
9	4 Sep 68	14.0	59	54	40	0.50
106	10 Sep 68	14.1	58	40	60	0.20
222	14 Sep 68	14.1	50	30	70	0.50
200	13 Sep 68	14.5	57	34	80	0.80
203	13 Sep 68	15.0	48	28	60	1.00
218	13 Sep 68	15.2	54	30	70	1.40
117	10 Sep 68	15.8	54	34	55	0.37
107	10 Sep 68	15.8	64	38	50	0.67
205	13 Sep 68	16.0	58	36	50	0.25
215	13 Sep 68	16.1	63	30	60	0.90
202	13 Sep 68	16.1	50	30	60	0.33
111	10 Sep 68	16.2	56	36	75	0.38
12	4 Sep 68	16.2	63	57	20	0.12
61	7 Sep 68	16.3	78	69	50	0.75
38	6 Sep 68	16.3	75	60	98	0.25
108	10 Sep 68	17.1	62	36	70	0.25
3	4 Sep 68	17.2	88	53	80	0.50
75	7 Sep 68	17.6	91	68	70	0.50
214	13 Sep 68	18.0	56	32	50	0.90
7	4 Sep 68	18.1	77	64	80	1.25
116	10 Sep 68	18.2	60	34	50	0.50
115	10 Sep 68	18.8	62	30	45	0.50
118	10 Sep 68	19.2	66	36	50	0.25
76	7 Sep 68	19.5	110	44	80	0.13
11	4 Sep 68	19.5	80	68	45	Not recorded
95	10 Sep 68	20.1	88	38	Neg*	Neg*
99	10 Sep 68	21.1	81	42	10	0.06
31	6 Sep 68	21.3	69	59	Neg*	Not recorded
201	13 Sep 68	22.5	59	47	0	0.0
81	7 Sep 68	22.7	106	57	55	0.12
94	10 Sep 68	22.8	114	64	0	0
46	6 Sep 68	22.8	84	69	55	0.88
5	4 Sep 68	22.8	106	87	50	0.20
39	6 Sep 68	23.2	73	60	96	0.25
6	4 Sep 68	23.5	96	70	75	0.75
74	7 Sep 68	24.7	117	50	80	0.33
34	6 Sep 68	25.5	64	58	40	1.00
42	6 Sep 68	26.3	98	50	25	0.25
100	10 Sep 68	26.4	80	40	60	0.50
73	7 Sep 68	26.7	123	80	75	0.37
45	6 Sep 68	28.6	98	65	50	1.00
29	66 Sep 68	28.7	78	70	30	1.00

*Negligible

DOUGLAS-FIR—FARMHAND SHAKER

Tree no.	Date	Dbh inches	Total height feet	Crown height feet	Cone removal percent	Cone removal bushels
104	10 Sep 68	11.1	52	44	60	0.20
211	13 Sep 68	11.1	55	31	70	0.52
13	4 Sep 68	11.5	68	56	30	0.50
220	14 Sep 68	12.0	50	35	35	0.25
213	13 Sep 68	12.8	49	27	50	0.60
210	13 Sep 68	13.9	53	33	60	0.45
219	14 Sep 68	14.0	45	20	65	0.50
47	6 Sep 68	14.0	75	54	80	1.75
216	13 Sep 68	14.3	51	21	30	0.30
85	9 Sep 68	14.5	70	51	8	0.02
84	9 Sep 68	15.3	71	58	5	0.02
80	7 Sep 68	15.4	98	36	10	Not recorded
217	13 Sep 68	15.6	49	33	45	0.56
87	9 Sep 68	17.3	102	69	5	0.13
75	7 Sep 68	17.6	91	68	40	0.25
41	6 Sep 68	17.9	91	60	30	0.75
43	6 Sep 68	18.0	92	79	45	0.50
212	13 Sep 68	18.7	53	35	20	0.30
77	7 Sep 68	19.3	98	48	10	Not recorded
79	7 Sep 68	20.0	112	45	40	0.25
99	10 Sep 68	21.1	81	42	10	0.06
5	4 Sep 68	22.8	106	87	50	0.20

PONDEROSA PINE—SHOCK WAVE SHAKER

Tree no.	Date	Dbh inches	Total height feet	Crown height feet	Cone removal percent	Cone removal bushels
120	11 Sep 68	7.0	40		5	Neg*
127	12 Sep 68	10.6	40		50	Not recorded
130	12 Sep 68	10.6	70		60	Not recorded
128	12 Sep 68	11.6	50		50	Not recorded
310	17 Sep 68	13.8	60	47	72	0.32
126	12 Sep 68	14.0	40		40	0.50
308	17 Sep 68	14.3	49	44	85	0.58
307	17 Sep 68	15.1	64	44	81	1.02
301	17 Sep 68	15.7	51	44	69	0.29
305	17 Sep 68	17.1	68	53	78	0.60
309	17 Sep 68	19.1	61	54	Neg*	0.14
306	17 Sep 68	19.6	74	51	64	0.97
303	17 Sep 68	22.0	70	61	Neg*	0.05

*Negligible

PONDEROSA PINE—FARMHAND SHAKER

Tree no.	Date	Dbh inches	Total height feet	Crown height feet	Cone removal percent	Cone removal bushels
121	11 Sep 68	7.0	40		0	0.0
122	11 Sep 68	11.0	45		0	0.0
312	19 Sep 68	12.0	70	62	Neg*	5 cones
123	11 Sep 68	14.0	40		0	0.0
311	19 Sep 68	16.0	80	20	Neg*	3 cones

*Negligible

ENGELMANN SPRUCE–SHOCK WAVE SHAKER

Tree no.	Date	Dbh inches	Total height feet	Crown height feet	Cone removal percent	Cone removal bushels
17	5 Sep 68	17.0	81	33	99	0.25
20	5 Sep 68	17.1	91	58	65	1.00
49	6 Sep 68	18.6	92	63	55	1.12
59	6 Sep 68	18.8	110	85	50	0.50
83	7 Sep 68	19.8	105	85		1.00
66	7 Sep 68	20.2	111	93	60	0.50
21	5 Sep 68	20.4	97	60	30	0.33
22	5 Sep 68	21.0	90	56	80	0.50
23	5 Sep 68	21.1	96	59	75	0.75
16	5 Sep 68	22.7	85	65	50	0.50
98	10 Sep 68	24.3	91	55	98	Not recorded
28	5 Sep 68	25.7	125	88	90	1.50
18	5 Sep 68	27.9	107	92	40	1.50
24	5 Sep 68	28.2	106	55	85	0.50
27	5 Sep 68	30.5	104	94	60	2.50

ENGELMANN SPRUCE–FARMHAND SHAKER

Tree no.	Date	Dbh inches	Total height feet	Crown height feet	Cone removal percent	Cone removal bushels
53	6 Sep 68	14.3	74	46	95	Not recorded
103	10 Sep 68	15.2	65	34	40	0.13
19	5 Sep 68	15.9	90	60	70	1.25
50	6 Sep 68	16.0	80	58	55	Not recorded
25	5 Sep 68	16.6	80	70	20	0.25
67	7 Sep 68	17.2	109	90	40	0.50
48	6 Sep 68	18.2	96	70	60	1.50
101	10 Sep 68	18.5	82	38	75	0.33
66	7 Sep 68	20.2	111	93	60	0.50
21	5 Sep 68	20.4	91	58	65	0.33
102	10 Sep 68	20.7	87	44	30	0.17

APPENDIX B

RELATIONSHIP OF CONE REMOVAL TO PARAMETERS

METHOD

A digital computer was programmed to derive least squares equations indicating the relationship of cone removal to several other parameters. Two other values, S_y, the standard error of y and r^2, the square of the correlation coefficient, were also computed. Table 2 presents the least squares equation, S_y and r^2 for each shaker for each species of tree. The independent variables presented are dbh, tree height, crown height/tree height, and dbh/tree height.

S_y indicates the precision of the equation. That is, for trees having a given X measurement, 67 percent will yield the predicted amount of cones $\pm S_y$. The smaller S_y produces a better prediction from the equation. The correlation coefficient squared, r^2, indicates the percentage of the variation in cone removal that is due to the parameter being considered. For example, we can use the information in the table to compute the expected harvest of cones from Douglas-fir as follows:

> To predict cone removal from a 10-inch dbh tree using the Farmhand Shaker, percent removal is, $Y = 76.4 - 2.54 \times 10 = 76.4 - 25.4 = 51$ percent. To check the accuracy of this figure, S_y is equal to 21.5, which indicates 67 percent of the 10-inch dbh Douglas-fir trees will yield 51 ± 21 percent of the cone crop using the Farmhand Shaker.

A single parameter cannot be used for predicting cone harvest for all species.

Table 2.—*Equations for predicting cone removal*

SPECIES	SHAKER	PARAMETER X	S_Y	R^2	EQUATION Y = Cone removal X = Tree parameter
Douglas-fir	Farmhand	dbh	21.5	0.138	Y = 76.4 – 2.54 X
		Tree height	21.6	0.135	Y = 63.8 – 0.375 X
		Crown height	22.9	0.0274	Y = 50.0 – 0.207 X
		Crown height / Tree height	23.1	0.0110	Y = 26.4 + 15.5 X
		dbh / Tree height	23.0	0.0189	Y = 22.9 + 58.9 X
Douglas-fir	SWS	dbh	24.7	0.0284	Y = 69.1 – 0.903 X
		Tree height	25.1	0.00596	Y = 50.0 + 0.0293 X
		Crown height	25.1	0.00237	Y = 55.9 – 0.00772 X
		Crown height / Tree height	24.8	0.0211	Y = 68.3 – 24.0 X
		dbh / Tree height	24.3	0.0599	Y = 83.6 – 119.2 X
Ponderosa pine	Farmhand	This shaker not effective on this species.			
Ponderosa pine	SWS	dbh	34.9	0.00109	Y = 41.9 – 0.310 X
		Tree height	34.4	0.0314	Y = 10.5 + 0.481 X
		Crown height	34.8	0.00374	Y = 27.8 + 0.213 X
		Crown height / Tree height	33.6	0.0716	Y = 169.6 – 164.8 X
		dbh / Tree height	34.1	0.0477	Y = 78.8 – 151.6 X
Grand fir	Farmhand	dbh	6.1	0.137	Y = 79.1 + 0.791 X
		Tree height	6.5	0.0382	Y = 85.6 + 0.0786 X
		Crown height	6.5	0.0276	Y = 99.4 – 0.0743 X
		Crown height / Tree height	6.0	0.172	Y = 112.6 – 24.6 X
		dbh / Tree height	6.6	0.00935	Y = 90.5 + 16.9 X
Grand fir	SWS	dbh	16.7	0.323	Y = 121.4 – 1.57 X
		Tree height	17.5	0.257	Y = 122.0 – 0.348 X
		Crown height	17.8	0.226	Y = 117.4 – 0.423 X
		Crown height / Tree height	20.3	0.000473	Y = 93.1 – 0.362 X
		dbh / Tree height	19.8	0.0486	Y = 111.3 – 94.5 X
Engelmann spruce	Farmhand	dbh	26.4	0.0672	Y = 106.9 – 3.17 X
		Tree height	26.1	0.0888	Y = 98.1 – 0.527 X
		Crown height	25.5	0.132	Y = 80.4 – 0.476 X
		Crown height / Tree height	25.7	0.120	Y = 96.1 – 66.3 X
		dbh / Tree height	27.3	0.00448	Y = 37.5 + 66.8 X
Engelmann spruce	SWS	dbh	21.9	0.00366	Y = 59.0 + 0.304 X
		Tree height	21.8	0.0167	Y = 89.1 – 0.234 X
		Crown height	19.2	0.234	Y = 104.1 – 0.552 X
		Crown height / Tree height	17.2	0.385	Y = 132.6 – 96.7 X
		dbh / Tree height	21.7	0.0241	Y = 46.4 + 86.7 X

APPENDIX C
CORRELATION OF
CONE REMOVAL TO DBH
AND TREE HEIGHT

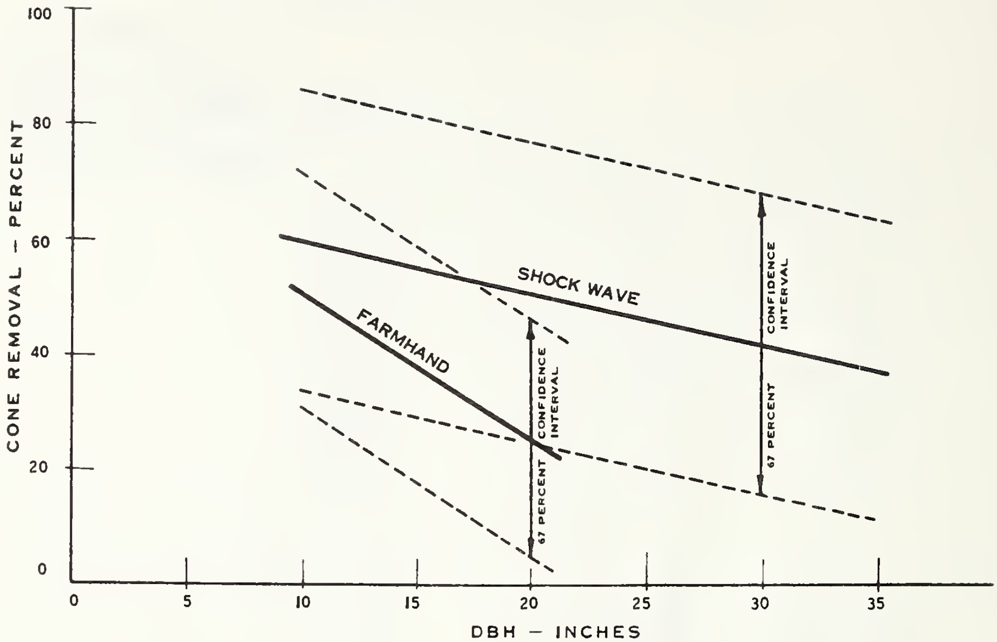

Figure 5.—Cone removal as a function of dbh for Douglas-fir.

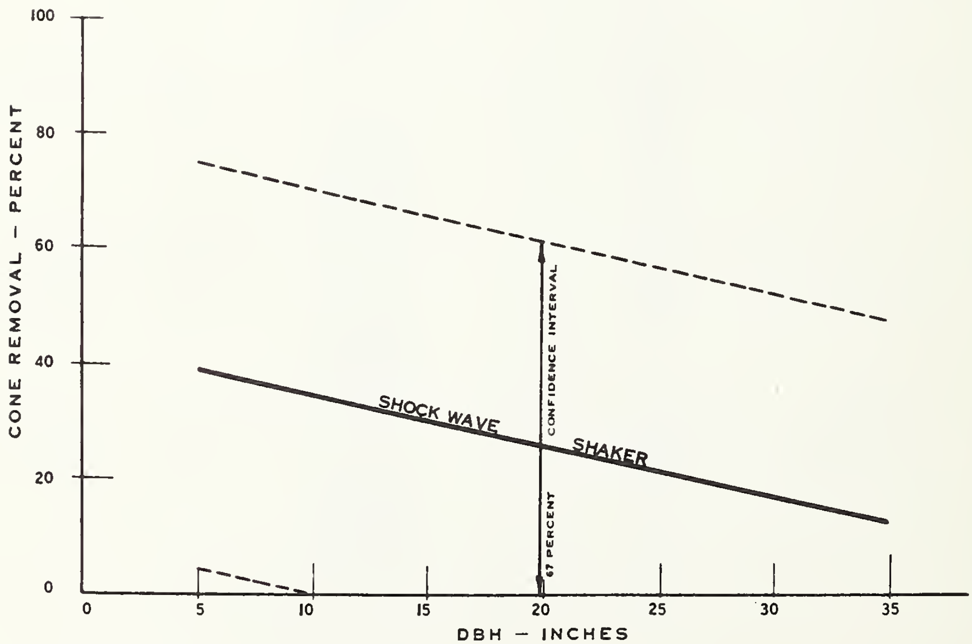

Figure 6.—Cone removal as a function of dbh for ponderosa pine.

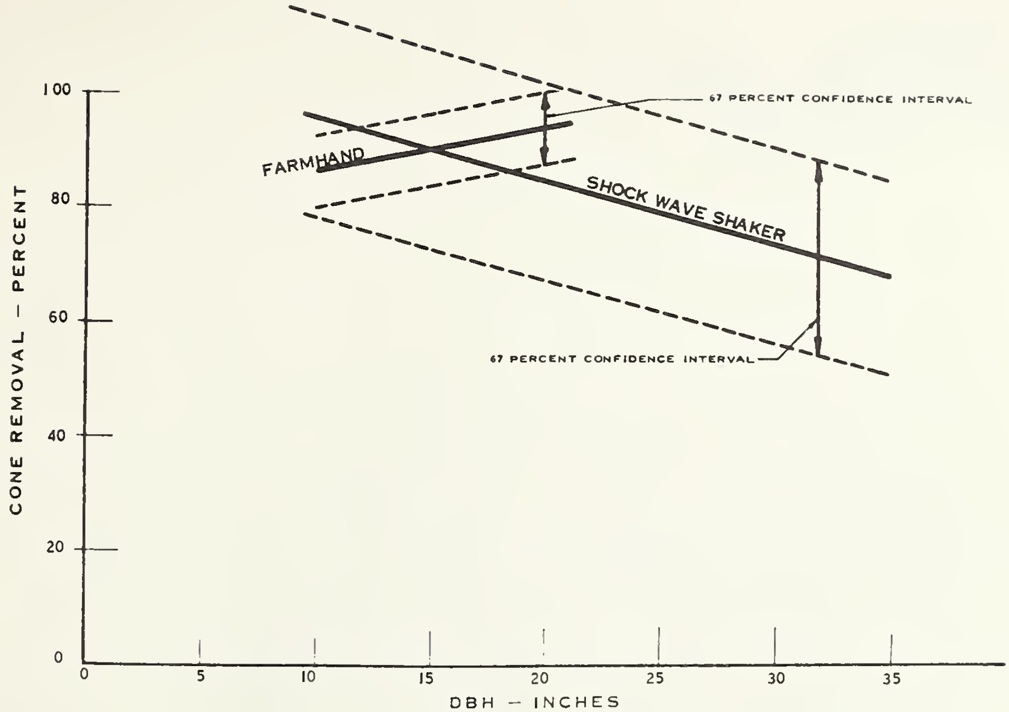

Figure 7.—Cone removal as a function of dbh for grand fir.

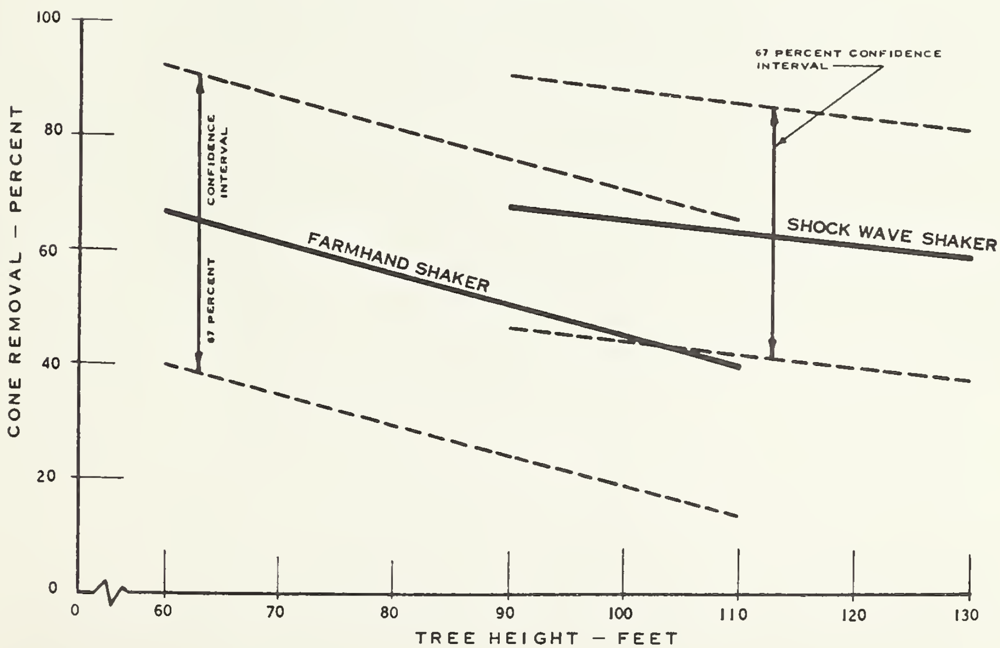

Figure 8.—Cone removal as a function of tree height for Engelmann spruce.

APPENDIX D
RADIAL DISPERSION OF DOUGLAS-FIR CONES

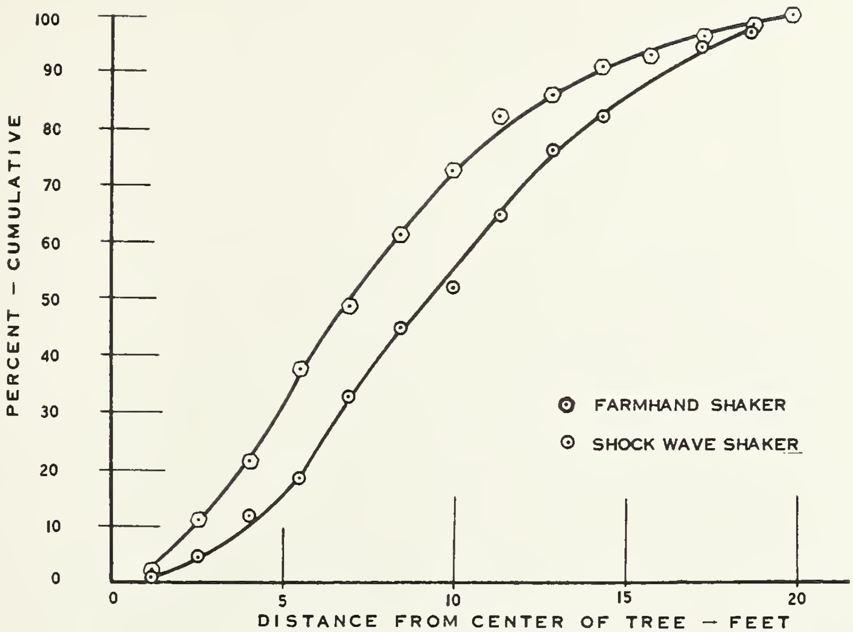

Figure 9.—Radial dispersion of Douglas-fir cones.

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